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By PETER G. PIRRIE

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HEAT AND ITS SIGNIFICANCE IN THE BAKERY

By PETER G. PIRRIE*

The statement has been made that heat and temperature are two different things only incidentally connected and dependent on each other. The scientist is in the habit of defining heat as the kinetic energy of the molecules of the body. In order to understand this statement it will be necessary to explain what the physicist means by the word molecule.

Based on the conclusions of a countless number of experiments it is generally assumed that all matter is made up of small individual particles, separate and distinct from each other and more or less free to move in and about each other. This may seem a very peculiar and extremely improbable situation; however, it may be easily seen that such an idea is only the logical result of a proper analysis of the situation.

THE MOLECULAR THEORY

Take a rod of iron. Saw this rod into two pieces. Each piece will have all of the properties of the original piece and about the only difference will be that there are now two pieces of iron where there was but one. If the process of dividing and sub-dividing the pieces of iron is continued, smaller and smaller pieces will result until eventually there will be obtained such a minute particle that it will be impossible to further sub-divide without destroying the nature of the substance. There must be a stopping place somewhere and this small, ultimate particle is that place. It is called a molecule and it is thought of as being the smallest particle of any substanec which can exist and still exhibit all of the properties of the original substance. These molecules are assumed to be in motion and the energy of this motion becomes evident to the senses as heat.

Without going further into details on the "molecular theory" as it is called, it may be stated that an increase in heat in any body simply causes an increase in the velocity of the molecules and a decrease in heat causes a decrease in the velocity of the molecules. This is evident in one of the practical effects of heat, namely, the property of expansion and contraction. If a body is heated the molecules move faster, and tend, on this account, to become more separated from each other, consequently the distance between the molecules becomes greater and the body becomes larger.

SPECIFIC HEAT

It is customary to define heat in terms of its effect upon water. Just as there are units of temperature, namely, the degree Fahrenheit or the degree Centigrade, so there are units of heat and in this instance the practical unit is the amount of heat which will raise the temperature of one pound of water one degree Fahrenheit. This unit is called the British Thermal Unit and is commonly spoken of as a "B. T. U." Now it is a peculiar fact that whereas one B. T. U. of heat

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will raise the temperature of one pound of water one degree Fahrenheit, it will raise the temperature of one pound of brass approximately 11° Fehrenheit, of a pound of gold approximately 33° Fahrenheit, and in a similar manner equal weights of different substances are all changed in temperature a different number of degrees by the application of the same amount of heat. A practical experiment will be useful in illustrating this peculiarity.

If one pound of water at 212° Fahrenheit and one pound of water at 32° Fahrenheit are mixed the resulting temperature is 122° Fahrenheit, which is because of the fact that one pound of water has been cooled down through 90 Fahrenheit degrees and one pound of water has been warmed up through 90 Fahrenheit degrees and the number of B. T. U. given off and taken up are equal. Whenever, equal weights of the same substance at different temperatures are mixed in this manner, a temperature practically half way between the extremes will be reached. However, on account of the fact that different substances have different capacities for absorbing heat, a totally different situation arises when two different substances at different temperatures are mixed. On mixing one pound of brass at 212° Fahrenheit with one pound of water at 32° Fahrenheit, the same conditions exist as in the preceding experiment with the exception that an equal weight of hot brass has been substituted for a pound of hot water. When the hot piece of brass has been suspended in the cold water in such a manner that all of the heat in the brass is contributed to the water the temperature of the mixture will not be 122° Fahrenheit but approximately 47° Fahrenheit. This result demonstrates that one pound of water warmed up only 15° while the pound of brass had to cool down 165° in order to furnish the heat necessary to warm the water that much. The one pound of water in warming up 15° needed 15 B. T. U. This amount of heat had to come from the pound of brass. Consequently, the pound of brass had to change in temperature 11 times the change in temperature of an equal weight of water in order to give off the amount of heat required. It is customary to say that brass, on this account, has only one-eleventh the heat capacity of water. This is expressed by a number which represents the relation to the heat capacity of water. It is called the specific heat of brass and is one-eleventh or approximately .09. This specific heat value is different for every different substance and the total amount of heat in any body is dependent not on temperature alone but on a combination of the weight, the temperature, and the specific heat of the body. It can readily be seen that this relationship is one of direct proportion. As the weight increases the amount of heat increases, as the temperature increases the amount of heat increases, and as the specific heat value increases the amount of heat increases. Mathematically therefore, we find that:

amount of heat = weight $\times$ temperature above a fixed point $\times$ specific heat.
(provided no change of state has taken place.)

BEHAVIOR OF OVENS

This offers an explanation of why it takes different amounts of coal to heat different ovens which are supposed to be of the same construction and why some ovens will hold the heat better and give a more uniform and steady baking temperature than others. Assume two ovens, supposedly absolutely identical, the same number of brick and the same weight of all materials being used in their construction. It is found that very considerably different amounts of coal are needed to bring these two otherwise identical ovens up to the same temperature and that when they are up to temperature, one of the ovens will hold the heat for a considerably longer time than the other. This may be very easily explained in that the materials in the one unit have a lower average specific heat value than in the other unit which makes it follow that less coal will be used in getting that particular oven up to heat, but that there will be a greater tendency to lose heat at the same time.

In order to get maximum heat efficiency from a bake oven, not only do the weights and specific heats have to be taken into account but also certain other features require consideration. It is a fundamental principle of heat that when one body is at a higher temperature than another heat will flow from the body of higher temperature to the body of lower temperature. This flow of heat takes place in three ways which are called convection, conduction and radiation.

CONVECTION

Whenever heat is moved bodily or mechanically from one place to another, the method is called convection. For instance, if a gallon measure of hot water is carried from one place to another, heat has been moved mechanically. Technically, this is convection. Convection is more familiar in connection with the heating of a room or in connection with the flue passages and chimney of a furnace. Whenever air is heated at any one particular locality, this heated air becomes lighter than the air around it and tends to rise. For instance, in a room the air in and about a radiator will become heated and will rise to the ceiling directly above the radiator. It will then pass horizontally across the ceiling, become cool, descend along the wall opposite the radiator and cross the floor back to the radiator to be reheated and recirculated. A similar situation exists in the bake oven where the air is heated at the grate, and is on this account caused to flow thru the flue passages and up the chimney. Such motion of air or other heated gases causes a mechanical transfer of heat from one place to another. This is spoken of in terms of "convection currents."

CONDUCTION

It is a similar fact that if a bar of metal is heated at one end the heat will travel through the metal and the other end will likewise become warm. When heat is transmitted through the substance of a body itself the process is called conduction. Just as different substances have different specific heats so do different substances have vastly different coefficients of heat conductivity. For instance, if one end of a copper wire is held in a hot flame, the other end of the wire will promptly become too hot to be held in the bare hand. However, if aluminum is substituted for the copper, the end of the aluminum wire can be melted off in the flame without the other end becoming too warm for the hand. The conductivity of copper is said to be very much higher than that of aluminum because it transmits heat much more rapidly.

RADIATION

The third manner in which heat may be transmitted from one place to another is by radiation. It is not necessary to touch or to be directly above a radiator to know that it is hot. The sense of heat will be obtained from a hot radiator even though one may be some considerable distance below or to one side of the source of heat. The heat is passed off directly from the radiator without the help of any convection current and without the necessity of any material possessing conductivity between. When heat is so transmitted from one place to another it is said to be radiated. Different substances and differently treated substances will radiate heat at different rates.

APPLICATION TO OVENS

When all of these factors are taken into account it is found that in practice not only the amount of heat must be dealt with, but also the physical constants of these hot substances in their connection with heat convection, conduction, and radiation. Tracing the heat relationships in a bake oven will give an understanding of all that takes place in heating up an oven and in baking bread. Coal is burned and a large number of B. T. U. are set free at the grate. These heat units are taken up by the air passing through the grate. This air becomes highly heated. Convection currents carry this highly heated air through the flues around the baking chamber and up the chimney. In the passage of this air around the baking chamber a considerable portion of the heat should be taken up by the materials of which the chamber is constructed. This heat will be taken up by virtue of the fact that the flue gases are at a higher temperature than the materials of the baking chamber. The heat will be taken from the flue spaces into these materials and through them to the inner surfaces of the baking chamber in accordance with the conductivity properties of these materials. If the coefficient of heat conductivity of the baking chamber construction is high, then the heat can readily pass from the flue gases to the place where it is used. If however, this coefficient happens to be low, then it will be just that much more difficult for the heat to get into the baking chamber proper and a considerable amount of it, on this account, will be lost up the chimney. Once the heat gets through the tile or brick of which the baking chamber is constructed, it gets into the baking chamber proper by radiation.

LOSS OF HEAT

Just as it gets into the baking chamber by radiation and conduction so can it also get out of the baking chamber and, if the oven is not properly constructed, the heat will flow by conduction through the walls to the outer surface of the oven and then radiate into the room. It is found by actual test that for a 600 loaf oven burning approximately 375 pounds of coal per day, the radiation loss from the peeling door alone may be as high as 110 pounds of coal, which means that there are burned for this oven 110 pounds of coal which are not assisting in any way whatever in the baking of the bread and are consequently a total loss. In addition to such a loss, if the walls of a bake oven are not properly insulated to the passage of heat, the heat will flow through these walls and out into the room. It is not logical nor is it practical to attempt to keep this heat inside the oven simply by increasing the thickness of the oven walls. Each layer of brick added to the oven walls simply increases the weight and requires that many more B. T. U. to bring the oven up to the same temperature. The proper method of keeping heat inside of a bake oven is to insert in the walls of the oven, substances which have a very low heat conductivity and which, on this account, are usually spoken of as heat insulators. Such materials are certain forms of mineral wool, air enclosed in a dead space, and certain forms of special brick. By proper construction and proper use of materials the conduction of heat through the walls may be reduced to a minimum and just that much more heat made available for conduction into the baking chamber itself. There is another point in the construction of a bake oven where heat may be readily lost. It is customary to build some ovens on piers of material which has a considerable capacity for conducting heat. Consequently the heat will flow through the body of the oven to these piers, down through the piers, and out through the floor. If something which will stop the flow of heat, is inserted into these piers, this loss can be prevented. Plate glass lends itself very readily to this purpose and ¾ or 1 inch of plate glass inserted in such piers will practically save all heat formerly lost at this point.

In this very rapid survey of an extremely important subject it has been pointed out that heat is a thing which must be watched very carefully, for if given the slightest chance it will go in directions and to places where it is not wanted. Furthermore it has been pointed out that by improper construction and wrong choice of materials heat may readily be prevented from going where it is wanted. Every time heat is given a chance to be lost and every time it is made more difficult for heat to get to the place at which it is to be used, the efficiency of the oven or other device will be lowered in proportion. This means money lost and fuel used to no good purpose. It behooves every baker to have a certain understanding of the nature of heat and its relationship to temperature that he may be better qualified to operate his equipment to the best advantage and put money into his own pocket.

TEMPERATURE, MEASUREMENT AND CONTROL IN THE BAKERY

The most important immediate application of heat in the bake-shop is in the production and maintenance of the proper temperatures during the different stages of the manufacture of bread. It should be realized at the beginning that heat and temperature are two different things, only incidentally connected and dependent on each other. Heat itself is a form of energy whereas temperature is merely an effect due to heat.

EFFECTS OF HEAT

Whenever additional heat is introduced into a body in one of the various ways, one of several different effects may be produced. The most common of these is an elevation or depression of temperature which is evident to the senses in that things are said to be hot or cold. Any body is said to be at a higher temperature than another when it will cause heat to flow from itself to the other body. However, a change of temperature is only one result due to addition and subtraction of heat energy itself. A change in state may result; for instance, the application of heat to ice melts the ice and the application of heat to water causes the water to change into steam and, during the entire time that the ice is melting as well as the time during which the water is boiling, there is no change of temperature in spite of the large amount of heat applied. It takes over five times the amount of heat to change a pound of water into a pound of steam (without any change of temperature at all) that it does to raise a pound of water from the freezing point to the boiling point. A third effect of heat which is very important is the property whereby bodies change in size with changes in the amount of heat they contain. This is easily illustrated by means of a tube of brass securely fastened at one end and free to move at the other. A pointer is connected at the free end of the brass tube in such a way that it moves over a scale with changes in length of the tube. If such an arrangement is set up and the pointer adjusted to a certain position, for ordinary room temperature, and then steam is passed through the tube by means of a boiler and proper connections, the temperature of the tube will rise. On this account it will become longer and the pointer will move across the scale. Most substances become larger and longer with an increase in temperature. There are a few exceptions to this rule which have their application in certain of the arts. Type metal is a familiar exception which increases in size with a decrease in temperature.

THERMOMETERS

In the measurement of temperature, two of the principles just discussed are used. When one body is at a higher temperature than another a flow of heat will take place from the former to the latter. Also when the temperature of a body rises it usually expands. A long, slender glass tube with a bulb at one end, into which is introduced sufficient mercury to fill the bulb and part of the tube, commonly known as a mercury thermometer, makes use of the latter principle and can be used to measure changes in temperature. Glass expands very much less for the same change in temperature than does mercury. On this account, if the temperature of the thermometer is raised the mercury will rise in the tube and if the temperature is lowered the mercury will fall in the tube. All common thermometers depend on this principle, with the exception that mercury is not always the liquid used. Mercury freezes at approximately 38° below zero, consequently a mercury thermometer cannot be used for temperatures lower than that point. Alcohol freezes far below any temperature met with even under unusual conditions and a thermometer can be made by using alcohol in precisely the same way as when mercury is used. The mercury thermometer has practical application to temperatures ranging from 38° below to 600° above zero Fahrenheit. The alcohol thermometer can be used at temperatures as low as minus 200° Fahrenheit, but is not efficient at temperatures above 173° Fahrenheit, as this is the boiling point of pure grain alcohol.

UNITS OF MEASUREMENT

So far temperature has been spoken of always in terms of Fahrenheit degrees. It is well to know how these degrees and the graduations representing them are obtained on the scale of a thermometer and how a thermometer, after having been purchased, can be checked up as to whether or not its readings are correct. It will obviously be necessary to have two points on the scale of any thermometer which are absolutely fixed. The process of obtaining these two points is called the "calibration" of the thermometer. Happily, in nature two such points are very readily obtained under perfectly controllable conditions. These are the melting point, and the boiling point of water. Under standard conditions of atmospheric pressure ice always melts at the same temperature and water always freezes at the same temperature, provided we are dealing with a mixture of pure ice and pure water in the same vessel. If the bulb of a thermometer is inserted into a mixture of pure ice and pure water after a short time the mercury will come to a constant level and will remain at this level as long as a uniform mixture of ice and water is maintained. This level at which the mercury stands under these conditions is marked on the stem of the thermometer and is called the freezing point.

When pure water is boiled, the temperature will remain absolutely constant as long as there is any water left and as long as the pressure which is allowed to exist above the surface of the boiling water is maintained constant. Investigators in physical science have determined the variations in the boiling point of water for variations in pressure so, that given the pressure existing, the temperature at which water will boil can be determined absolutely. Hence, by surrounding the bulb of a thermometer with steam from boiling water under known conditions of pressure, it is possible to locate another point higher up on the stem of the thermometer which, in ordinary language, is spoken of as the boiling point. Thus, are obtained two absolutely fixed points on the stem of a thermometer to which the mercury will return whenever the same conditions are reproduced. These two points are called the fixed points of the thermometer and if the distance on the stem of a thermometer between these two fixed points is divided into 180 equal parts, and the small divisions so obtained are extended both above and below the two fixed points a rational thermometer scale is constructed. When the freezing point is marked with the number 32 and the boiling point is marked with the number 212, the device becomes the thermometer with which the baker in this country is familiar and which is called the Fahrenheit thermometer.

It will be noted that the zero on the Fahrenheit thermometer is 32 Fahrenheit degrees below the freezing point. Scientists are in the habit of using a different scale. They divide the distance between the freezing point and the boiling point into 100 equal parts, mark the freezing point zero and the boiling point 100 and call the thermometer the Centigrade thermometer. This instrument has the advantage over the Fahrenheit thermometer in that it is divided according to the decimal system and has the freezing point marked zero.

CHECKING UP A THERMOMETER

Commercial thermometers, even of the better class, whether of the mercury or the alcohol variety are seldom correct. The variation between the reading given by the thermometer and the correct temperature existing may be a very considerable amount. Modern methods of manufacture, the piece work system, and rather slack methods of inspection, contribute to this situation and bakers should be particularly careful to know that their thermometers are correct and that when a dough thermometer says that the dough is at 80 degrees that the temperature actually is such. It is very easy to check the scale of a thermometer. All that is necessary to do is to place the bulb in a mixture of powdered ice and pure water and stir for two or three minutes, in this way determining the correctness of the freezing point. Then place the bulb of the thermometer in some pure water which is boiling in an open vessel and determine the temperature of the boiling watr. Local weather bureaus are prepared to give the correct temperature at which water boils each day. In this way it is possible to discover how far off an instrument is. However, unfortunately just because a thermometer is correct at the freezing point, and at the boiling point, is no indication that it will be correct at points between. A thermometer may be correct at the freezing point, correct at the boiling point and 4° off at 80°, which is exactly the point at which the baker needs accuracy.

In order to check a thermometer at any given temperature, for instance 80°, it is necessary to do one of two things. Either obtain

from the Bureau of Standards at Washington a thermometer with a certificate stating that it is actually correct, and check the working instrument against it or send the working thermometer to a laboratory which will determine whether or not the readings are as they should be. In either case the procedure will be the same. The temperature of a vessel of water is adjusted to 80° Fahrenheit with the standard instrument which is known to be correct, and then the working instrument is placed in the same water. Suppose that the standard instrument reads 80° and that the working instrument reads 82°, which is a common occurrence. The working instrument is shown to be incorrect. However, this is no reason why it should be destroyed or disposed of. If it is desired to run the doughs at 80°, the incorrect instrument can be used to control the temperatures, but it should indicate 82° as the test has shown that when the instrument indicates 82° the exact temperature is 80°.

THERMOSTATS

A liquid and glass thermometer is not the only instrument which can be used to indicate changes in temperature. If a rod of wrought iron is 100 feet long at the freezing point, and the temperature of this rod is increased to that of boiling water, it will be found to be approximately 100 feet, 1½ inches long. However, if the original rod had been zinc instead of iron it would increase in length not 1½ inches but about 3¼ inches. Thus it is seen that different metals change length in different amounts for the same change of temperature. Using this principle, it is possible to make an instrument called the "thermostat" which may consist of a strip of thin iron riveted to a strip of thin zinc throughout their entire lengths. If one end of this composite strip of metal is securely fastened and the other end is free to move, when the temperature is increased the zinc will curl around the iron strip and cause the entire bar to move to one side. If the temperature is decreased the opposite effect will be produced and the entire bar will curl to the other side. All that is necessary is to fasten a pointer to the end of such a composite bar of metal and an instrument which can be used to indicate changes in temperature is obtained. The motion of the strip of metal will cause the pointer to move and a scale can be arranged which will read directly in temperature. Such an arrangement forms the basis of a large number of indicating and recording thermometers, which, on account of their metallic construction and the absence of glass and liquid, will stand a greater amount of rough handling than the common thermometer. Furthermore, the thermostat can be used by suitable electrical connections to switch on a light or ring a bell for extremes of temperature, in this way acting as an alarm device. Instead of actuating an alarm system a thermostat may be used to make and break an electrical ccircuit and in this way regulate the temperature of ovens and other devices heated by electricity. The common oven pyrometer is a thermostat consisting of a composite tube of carbon and iron so arranged that a pointer is moved over a scale by a difference in the motions of iron and the carbon under changes in temperature.

ELECTRIC THERMOMETERS

A third principle for indicating temperature is used in the electric thermometer, called a thermo-couple. It is found that when two wires of dissimilar metals are twisted tightly together at one end and the free ends are connected to an instrument which will indicate delicate electric currents that even at ordinary temperature a small amount of current will flow as will be shown by the movement of the needle on the scale of the instrument. If the joint where the two metals meet is heated there will be a higher reading on the scale of the instrument and, correspondingly, a lower reading if the joint is cooled. This is a very accurate and convenient device for the measurement of temperature, particularly suitable for such places as a bake oven and for temperatures above the ordinary range of the common thermometer. Furthermore, there is a great advantage in that the instrument which tells the temperature may be placed at any desirable distance or any desirable location with respect to the thermo-couple itself which is located at the source of the heat. Such instruments are very accurate and an up-to-date bake shop should not be without one of them if it is used for no other purpose than to check up the action of the common pyrometers and thermometers installed by the oven manufacturers.

RECORDING DEVICES

An instrument which depends upon the thermostatic, metallic, or electric principles may have a small fountain pen attached to the end of the pointer in such a way that this pen travels over a sheet of paper. If this sheet of paper is moved across the path of motion of the pointer by a clock work so that the distance moved is proportional to the time, a continuous record of temperature is obtained at any point for any length of time. Such a device is called a Recording Thermometer. The sheets are commonly ruled for 24 hours and a new sheet is placed on the instrument at the end of each time period. These sheets will tell the temperature at the place the instrument is located for any instant, at any time and furnish an absolute check on any automatic temperature controlling device or on the manner in which the foremen in charge is regulating the temperatures of his doughs, dough room, proof box or oven. Temperature being so important a feature in the bakeshop of today, it is highly desirable that its nature, the method of its measurement, and the characteristics of the various commercial thermometers be understood by all bakers. Thermometers, or other temperature measuring devices in bake shops should be known to be correct and in their use care should be taken that errors, which can be avoided in the simple manner explained above, do not creep in.